

Assessment

Forest Plan Revision

Draft Soils Report

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Introduction: Soil Productivity and Management

Soil properties and land potential vary across natural landscapes at multiple scales in often complex yet predictable patterns. As landscape diversity increases so does the diversity of soils covering the landscape. In essence, differences in the soil are a reflection of the local environment, both past and present. Thus, soil and landscape are linked; you cannot manage one without affecting the other. While the Custer Gallatin's extraordinary mountains, wildlife, and landscape diversity are what typically catches the casual visitor's attention, a vital part of the Custer Gallatin's land resource lies hidden from view, literally at their feet—the soil. Inherent land and soil productivity, or land potential from a natural resource perspective, most often refers to the ability of the land to produce desired types and amounts of native vegetation.

In regulations, land potential is generally referred to as productivity of the land or soil. National environmental regulations, including the National Environmental Policy Act (NEPA) and the National Forest Management Act, mandate that productivity of the land (and soil) should not be permanently degraded as a result of Forest Service management activities. Thus, understanding the variability of those complex but predictable patterns becomes an important part of both good natural resource management and ensuring compliance with national environmental laws.

For the purposes of this discussion, landscape complexity is defined as the overlapping influences of geology, terrain, and local climate. Not coincidentally, those same factors are primary drivers of soil potential as well as soil formation in young landscapes, such as the Northern Rocky Mountains. These will be discussed in further detail. Each factor is distributed differently across the landscape and each has its own unique effect on environmental conditions. The resulting landscape one looks at may be simple or complex based on the interaction among these factors, but nearly all landscapes contain gradients in environmental conditions as well as boundary areas where very different environments meet.

Processes and Methods

Current approaches used on the Custer Gallatin National Forest to analyze soil resources and to quantify management impacts to land productivity are discussed in this section. For soil and land resource analysis, the concept of a "soil-landscape" has been used to great advantage at various scales on the Custer Gallatin both from an analysis standpoint and for generating soil interpretations specific to forest needs. The concept of detrimental soil disturbance was first appeared in the 1999 Region 1 Supplement to the Forest Management Act (USDA-R1 1999). Detrimental soil disturbance provided a metric for assessing potential loss of land productivity due to management activities; thus, a critical component for compliance with national environmental laws that govern management of Forest Service lands. Combined, the concepts of soil-landscapes and detrimental soil disturbance provide a sound basis for both assessing inherent land productivity (land potential) and the potential loss of that potential due to management activities.

Soil-Landscapes

The concept a soil-landscape has increasingly been used on the Custer-Gallatin Forest as the appropriate data element for NEPA analysis, project work, and the inventory of soil and land resources at various scales. For forest management purposes, we define the term "soil-landscape" to mean an area of land underlain by a specific type or combination of geologic parent materials (rock type and/or mode of deposition) that exhibits a distinctive pattern of landscape attributes, such as the pattern of terrain features and/or the distribution of plant communities. There may be multiple soil-landscapes occurring

on any one geologic parent material, but each will exhibit a common subset of features reflecting the underlying geologic material and local climate conditions. These features include properties of the soil as well as the type or types of vegetation present.

The concept of soil-landscapes has been used on the Gallatin Forest for numerous projects over the past 7 or 8 years for the analysis of soil resources at various scales. These have ranged from 1:100,000 for a preliminary analysis of soil resources in the Absaroka-Beartooth Wilderness down to a 1:6,000 scale for native grassland restoration work in the Gardiner Basin. The Gallatin National Forest first started using the approach due to deficiencies in the available soil survey data for the Forest. The concept itself, as applied on the Forest, has evolved during this period to meet various soil resource information needs.

The use of soil-landscapes as a data element recognizes that soil and landscape are inextricably linked. As national forests manage landscapes they also manage soils. A soil-landscape is something visible in the field (with some training). It can be readily mapped on aerial photographs or higher quality satellite imagery. And since by design soil-landscapes are based on the very same landscape factors—geology, terrain, and local climate, which are the primary drivers of soil formation—they contain a wealth of information about soils, soil properties, and the distribution of those properties at a landscape scale. The approach lends itself well to utilizing various sources digital data, such as terrain modeling results and color infrared imagery to both delineate map units and characterize soil resources within those units. The Custer Gallatin recently has adapted its approach to address the problem of how to scale map results up and down without losing information or misrepresenting map results. Thus, the same basic input data can be used to create map products at multiple scales.

The concept also has applicability for updating existing soil survey information or creating new soil survey information in unmapped areas such as the Absaroka-Beartooth Wilderness. The same basic approach has been used on the Gallatin portion of the Forest at a project scale for NEPA analysis of proposed timber and range management projects. It provides a very clear way of presenting differences in soil properties that affect soil and land resources at a land management scale while avoiding the use of often complicated soils jargon or soil series names. Lastly, the level of soils information generated can be tailored to directly match what is needed for NEPA analysis as well as project management.

Detrimental Soil Disturbance

Although enhancing the productivity of Forest Service lands has been mandated by NEPA since 1969 (16 USC § 4321) and the National Forest Management Act since 1976 (16 USC 472a), it was not until a region-wide detrimental soil disturbance standard was established in 1999 that an actual mechanism was put in place to limit activity-caused soil disturbance. The 1999 R-1 Supplement to the Forest Service Manual (USDA 1999) not only established detrimental soil disturbance as the metric to assess potential reductions in the productivity, but also set a maximum limit of 15 percent allowable detrimental soil disturbance within treatment areas. The standard applies to the both pre-existing and current activity-caused detrimental soil disturbance. Use of detrimental soil disturbance for NEPA analyses is based on an underlying assumption that soil and land productivity will be maintained so long as less than 15 percent of the area is detrimentally disturbed. An analogy can be made to croplands. Some portion of the land will be disturbed by activities needed to establish, maintain, and harvest the crop. This loss of the tillable land is allowable so long as only a limited amount of the overall land base is affected.

Different types of detrimental soil disturbance are identified in the Region 1 Supplement (USDA 1999); soil compaction, displacement, rutting, severe burning, surface erosion, loss of surface organic matter, and soil mass movement. The 15 percent standard applies to all areas on the Custer Gallatin where growing vegetation is the prime objective. The standard does not apply to intensively developed sites,

such as mines, active gravel pits, or administrative sites (USDA Forest Service 2009). Initial criteria were presented to aid in the identification of detrimental soil disturbance. A wealth of information has been developed over the last 40 to 50 years about the negative effects that some timber harvesting and other activities can have on soils under varying soil and environmental conditions. The following represents just a portion of the published literature on this topic: Klock (1975); Clayton et al. (1987); McIver and Starr (2000); Powers et al. (2005); Han et al. (2009); Miller et al. (2010). The best currently available approach to assess trends in detrimental soil disturbance across the Custer Gallatin is to look at the trends that have occurred in timber management activity, both type and extent, during the last 30 to 35 years on Forest Service lands and put this information in context with the growing understanding about the relationship between management activities and soil impacts. It is in this context that high quality, site-specific, soil monitoring data of detrimental soil disturbance levels can be used as an invaluable reference dataset.

Detrimental soil disturbance assessments on the Custer National Forest have utilized the Forest Soil Disturbance Monitoring Protocol (Page-Dumroese et al. 2009) since 2009. The Forest Soil Disturbance Monitoring Protocol method was designed to provide a statistically valid, rapid assessment of soil conditions based on visual indicators to describe surface conditions that affect site sustainability, hydrologic function, and site productivity. In addition, the Custer National Forest describes the soil type or types within project areas from a soil survey to better interpret where long-term soil impairment may occur.

The Gallatin National Forest (Keck 2009) refined the indicators of detrimental soil disturbance so they can be consistently applied in the field on the basis of readily measured field data and correlated to observable changes in site productivity and/or soil function. The goal of this work was to improve the consistency of results among different soil scientists. The 2009 document contained specific criteria for the field identification of detrimental soil disturbance as well as updated soil and best management practices for the Gallatin. Subsequent updated versions released in 2011 and 2012 (Keck 2011, 2012) to include further refinements. Of specific concern was the criterion in the R-1 Supplement that required either the measurement of bulk density or unverified field determinations based solely on the judgement in the field soil scientist.

Bulk density, although conceptually very simple, can be extremely difficult to accurately measure in the field under varying soil conditions. This is especially true in soils that contain abundant rock fragments which accounts for approximately 75 percent of the soils on the Gallatin National Forest. Results more often than not reflect the method used as much as actual differences in bulk density between separate studies. In the same manner, relying on field judgement calls without measurable quantitative data or criteria can result in substantial differences among different soil scientists. Adjustments made to the basic soil monitoring procedure were aimed at addressing these as well as other data collection concerns.

The majority of areas where detrimental soil disturbance has been monitored on the Custer Gallatin have been past timber harvest areas. The basic Gallatin National Forest procedure has also been used for both rangeland and riparian detrimental soil disturbance evaluations. The Custer National Forest has used a variety of procedures for assessing detrimental soil disturbance for non-timber harvest management activities, including both range assessments and prescribed burning.

All soil disturbances are currently considered to be negative, with some types worse than others. However, soil disturbance can be viewed as a management tool to reduce soil erosion when utilized appropriately or to enhance the establishment of certain desired species that require ground disturbance for propagation.

Current Forest Plan Direction

Forest plans for both the Custer and Gallatin portions of the Custer Gallatin National Forest provide limited direction with respect to the management of soil resources. Between the two forests, the direction can be paraphrased as follows:

- 1) Maintain soil resources and watersheds in a desirable condition,
- 2) Maintain or improve soil productivity,
- 3) Best management practices will be applied, and
- 4) The Forest soil survey will be incorporated into resource analysis (USDA Forest Service 1987a; USDA Forest Service 1987b).

As a result of limited guidance at the Forest level, procedures followed rely primarily on regional guidance, the professional expertise of soil scientists currently working on the Custer Gallatin and their ability to use best available science to maintain the productivity of soil and land resources.

Scale

The scale used for this analysis is roughly 1:100,000. At this scale, the variables that define soil landscapes become most apparent at the forestwide scale.

Existing Information Sources

Soil Survey Data. Multiple soil surveys of varying age, quality, and type cover portions of the now-combined Custer Gallatin National Forest. Table 1. provides a summary of the soil surveys covering the Custer Gallatin National Forest. Each soil survey on its own might be considered as the best usable information solely based on its availability within in an existing database. Individual soil surveys, however, vary widely in terms of mapping procedures used, accuracy and precision of map unit concepts, the quality and resolution of field mapping and ability to generate accurate soil interpretations.

Table 1. Soil survey areas and currently available soil surveys covering Forest Service lands on the Custer Gallatin National Forest

Soil Survey Area	Date Issued	Field Work Conducted	Survey Type ¹
Carter County, Montana	2003	Approximately 1983 to 1990	County
Gallatin National Forest, Montana	July 1996	1976 to 1980	Landtype+
Rosebud County and part of Big Horn County, Montana	June 1996	Approximately 1974 to 1982	County
Harding County, South Dakota	1988	Approximately 1977 to 1983	County
Carbon County, Montana	1975	Approximately 1962 to 1968	County
Powder River, Montana	1971	Approximately 1960 to 1964	County
Abasaroka-Beartooth Wilderness and adjacent Beartooth District lands	None	No field mapping completed	No soil survey available

¹ Countywide soil surveys were conducted by the Natural Resources Conservation Service (formerly Soil Conservation Service). Soils are mapped by interpreting landscapes and sampling soil profiles in the field. Map unit concepts are developed during field mapping and utilize soil series as the primary data element.

Despite the above noted deficiencies, soil information from the soil survey of the Gallatin National Forest is always reviewed and often presented in the soils NEPA analysis of projects on the Gallatin. These data have most often been dismissed in the analysis, however, due to their inaccuracy and lack of sufficient resolution. Soils information from the soil survey is then replaced by soil-landscape information obtained during field assessments of project areas with the support of reference information from the following sources: Montana Bureau of Mining and Geology Geologic Quads, archived aerial photographs, topographic quads, and on occasion, terrain modeling results, which are used to fill in gaps in the available field information. This soil resource information developed from supporting data sources and available expert knowledge is currently the best available soil information on the Gallatin.

The soil survey information available on the Custer portion of the Forest, although fragmented, provides higher quality soils data and more directly satisfies the needs for soil resource information than the landtype soil survey information available on the Gallatin. At this time, the primary, best available soils information on the Custer is represented by a mosaic of different countywide soil surveys covering Forest lands on the Custer in combination with institutional knowledge of Forest personnel.

Other Sources of Land Resource Information. A wide range of other types of spatial data are available that can be useful in the assessment of soil and land resources. The most valuable of these are flagged in Table 2. . Outside sources of information may augment the information available in a soil survey or several data layers may be used together along with expert knowledge and some field sampling to fill in gaps within in the existing soil survey information. A critical component in this work would be access to the appropriate expert knowledge in the following disciplines: soils, soil mapping, soil genesis, and advanced mapping techniques.

Table 2. provides a summary of the most common spatial analysis coverages and resource data available to the Custer Gallatin. All of the data sources listed in Table 2. are currently available to and a number are used by the Custer Gallatin to fill information gaps in the available soil survey data. These sources can be used to supplement existing soil survey data or when used in conjunction with field reconnaissance to replace inaccurate or incomplete soil survey data.

Each data source has strengths and weaknesses in regard to predicting soil properties and related land attributes at a landscape scale. In nearly every instance, however, the information provided relates directly to one or more soil-forming factors that play an important role in determining the distribution of soils on the Forest. As such, each data layer contains a certain amount of predictive, spatial information about the soil resource. When combined together along with targeted field sampling and the use of appropriate analytical procedures they provide a solid basis for modeling the distribution of soils and can be used to generate higher quality soils information than currently available in most of the soil surveys covering the Forest at this time.

Table 2. Additional sources of land resource data/information

Source Data	Data Types	Notes
Topographic Maps ¹	USGS topographic quads	Typically 1:24,000 scale but smaller scales also available
Geology Maps ¹	Montana Bureau of Mining and Geology geology maps ¹	Mapping of each quad is often independent of surrounding quads, making edge matching difficult
	USGS geology maps	May have similar edge matching problems
	Soil-landscape potential maps ¹ based on modified Montana Bureau of Mining and Geology geology coverages	Modified Montana Bureau of Mining and Geology Quads that have been correlated to identify predominant soil-landscape types and land potential differences on Forest Service lands
Aerial Photography†	Rectified photography	Aerial photography rectified to eliminate scale differences due to topographic relief; can be input into a GIS coverage and adjusted to any specific scale and/or map coordinate system
	Archived color or black and white aerial photography ¹	Color or black and white aerial photographs that has not been rectified allowing the imagery to be viewed in three dimensions (stereo) with use of a stereoscope; commonly used for soil mapping prior to about 1990
	Color infrared imagery ¹	Aerial photography, most often taken in August with infrared film, used to identify areas where extra soil water is available to plants based on photosynthetic activity
Weather Station Data†	Standard climate data	Valuable reference data of past annual and monthly weather conditions going at site locations; number of appropriate weather stations available can be limited for some areas
Indicator Species ¹	Use of specific plant species to identify local climate conditions	Predictions can be quite accurate in some instances but by may be confounded at times by other factors, such as differences in local geology
Terrain Analysis ¹	Based on either 30 meter ¹ or 10 meter data	Many terrain variables can be calculated and displayed as coverages. Slope, aspect, and elevation are most commonly used other terrain variables may be more valuable in some applications. Smaller grid size data not relevant a landscape scale
Satellite Imagery ¹	Low resolution	Small-scale disturbances that get blended into the background often disappear leading to false interpretations; computer generated imagery instead of photographs; can be readily projected into a coordinate system
	High resolution	Still a computer generated image based on spectral scanners but with a high enough resolution to keep small scale features visible
Climate Models	NRCS climate models and prediction tools	Numerous models likely exist; accuracy will depend on location, proximity to weather stations, and the model used

¹ Information commonly used in the analysis and field interpretation of soil resources and development of soil landscape concepts.

Terrestrial Ecological Unit Inventory

The Forest Service has direction to create Terrestrial Ecological Unit Inventories as needed that will closely define the relationship between soils and native plant communities within land units (Winthers et al. 2005). The Custer portion of the Custer Gallatin has completed vegetation sampling needed to create a Terrestrial Ecological Unit Inventory for lands in the Beartooth District, including the Custer portion of the Absaroka-Beartooth Wilderness. These data provide high quality information about vegetation resources for the areas sampled. This inventory requires that corresponding soils data to be collected that meets National Cooperative Soil Survey standards for classification, description, and

documentation (Winthers 2005). To date, National Cooperative Soil Survey staff for the Northern Rocky Mountain Region have not certified the soil data for this project due to a lack of appropriate soil map unit concepts and deficiencies in soil field mapping procedures used (Karinen, J., 2016, Northern Region, Data Quality Specialist, personal communication). The Custer Gallatin currently has a proposed plan in place to rectify these deficiencies once the opportunity exists. Good quality, point sample soil profile data was collected as part of the initial field work for this project. These data will be useful in helping complete the Terrestrial Ecological Unit Inventory.

Watershed Condition Assessment

The Watershed Condition Framework uses 12 indicators to rate 6th-order watersheds (HUCs) covering all Forest Service lands in the United States. Watershed size can vary tremendously at the 6th-order level, depending on characteristics of the landscape and drainage patterns. For the Custer Gallatin, ratings were assigned to watersheds ranging in size from 8,000 to 50,000 acres. Soil condition is just one of those 12 indicators used of Watershed Condition Framework. Three sub-categories were analyzed to determine soil condition; these are: soil productivity, soil erosion and soil contamination. Initially, the watersheds were ranked across the United States in 2011 and 2012. The analysis overall should be considered as semi-quantitative at best even though improvements were made on the Custer Gallatin National Forest to utilize available quantitative data as the basis for the ratings to the extent possible. One of the limitations of the overall analysis from a Forest perspective is the use of 6th-order HUCs as the resolution for reporting results. While 6th-order HUCs provide an appropriate basis for reporting hydrology and fisheries results, soil impacts that occur more at a local scale can get washed out at the 6th-order HUC scale. As a result, the Watershed Condition Class results generally do not provide useful knowledge at the Forest level and as a result, are not included in the current existing information assessment for Soils.

Existing Condition

Much of the discussion in this report revolves around issues of reduced land productivity. As noted at the start of this report, a basic question needs to first be answered about the inherent capability of lands within the boundaries of the Custer Gallatin National Forest, to produce desired types and amounts of native vegetation. Soil productivity depends in part on the plant species and/or plant community present on the site. A highly productive soil for one plant community type may not necessarily be productive for a different community type. Overall generalizations can be made, however, about soil and landscape factors that contribute to increased site productivity in general for most plant communities on the Forest. For many plant species, ideal soil and site conditions include:

- The appropriate soil texture for the desired plant species/community type with some rock fragments in the soil but not too many.
- Appropriate soil pH for the desired species, e.g., lodgepole pine (moderately to strongly acidic), and Douglas-fir (mildly to moderately alkaline).
- Primarily deep to very deep soils (most species).
- Moderately well drained, i.e., evidence of an ephemeral high water table within 72 to inches of the soil surface, or well-drained soil conditions (highly dependent on the species present).
- Run-in landscape positions (areas where water accumulates in the soil from upslope positions).
- No other limiting factors, such as soil contamination or saline/sodic soil conditions, are present.

Appropriate levels of forest litter and coarse woody debris in the soil can improve conditions for conifers on a site, but these can build up over time with proper management. Inherent productivity of the soil is more a function of rooting depth, and chemical and physical properties of the soil than transient factors such as litter layer thickness. For every condition noted above there are exceptions. For instance, bitterbrush (*Purshia tridentata*) lives almost entirely on very shallow to shallow soils in all areas sampled by the author. Other species thrive on soils with abundant rock fragments. But for many plant species the soil conditions listed above would be considered optimum. Please note most of the statements above have some type of conditional clause added such as “appropriate for the desired species”. Differences in plant communities types are often be used as an indicator of soil differences in mapping soils once relationships have been verified.

Changing Landscape Conditions from West to East

Across the Custer Gallatin National Forest in general, there are very few areas where inherent soil productivity is not limited by one or more natural constraints. Soil productivity over most of the forest west of the Pryor Mountains can be characterized as limited by a cold-dry climate, steep terrain and abundant shallow and/or rocky soils. Productivity is limited by cold soil temperatures in the spring and dry soil conditions during late summer and early fall months of most years. Analysis of soil map units used in the soil survey of the Gallatin National Forest (USDA-Forest Service 1996) show that as much as 75 to 80 percent of the total land area on the Gallatin contain abundant rock fragments (greater than 35 percent by volume) throughout most of the soil profile. Given the type of physiography, high elevation, bedrock materials, and climate, it is reasonable to assume that unmapped areas of the Absaroka-Beartooth Wilderness and adjacent non-wilderness portions of the Beartooth District have the same constraints on inherent land productivity as Custer Gallatin lands to the west.

Conditions change dramatically on the east side of the Custer Gallatin. Forested lands located on the Ashland and Sioux Districts are characterized as warm and dry. Both the Ashland and Sioux Districts are located on the high plains east of the Rocky Mountains in a landscape comprised of dissected plateaus surrounded by lower elevation upland and alluvial landscapes. These relicts of eroded Tertiary age, marine geology are largely composed of sedimentary sandstone and shale. Inclusions of baked shale (locally called scoria or clinker rock), coal, and volcanic ash tuff added some additional geologic diversity over portions of the area. Landscapes in these areas are characterized by lower elevation hills (mountains), dry plains and badlands. Perennial drainages are mostly slow moving rivers and streams with ponderosa pine as the dominant forest species.

Soil moisture deficits during late summer and early fall months restrict site productivity in most areas on the Ashland and Sioux Districts. Soil temperatures are warmer in the spring than western portions of the Custer Gallatin, which results in an overall longer growing season. The soil types on the lowland plains areas tend to have finer soil textures associated with greater amounts of shale parent materials than the surrounding plateau and hill areas. The finer textures increase water holding capacity in these low lying areas but the combination of lower precipitation levels, restricted drainage, and soluble salts originating from the shale can result in saline and/or sodic soil conditions that can drastically reduce productivity. Saline and sodic soil conditions exist primarily in low sloping areas adjacent to shale uplands.

The amount of hard rock fragments in soils depends on hardness of the parent rock. Since plateau and mountainous areas are most often the result of resistant bedrock, soils in those areas tend to contain more rock fragments than those on the shale or soft sandstone landscapes. Abundant shallow soils near bedrock outcrops and on most south-facing escarpments limit productivity, while at the same time potentially increasing local vegetation diversity on both the Sioux and Ashland Districts. Productivity in

lower elevation lowlands areas is limited by saline and/or sodic soil, hotter temperatures during the summer and overall lower amounts of mean annual precipitation during most years.

The Pryor Mountains provide a unique middle ground between the two sides of the Custer Gallatin. Broad, grass covered, mountaintop areas at the highest elevations are underlain primarily by hard limestone bedrock while lower elevation, mountain flanks are mostly limestone and sandstone. The most limiting factors on inherent soil production in the Pryor Mountains are soil water deficit in the late summer and fall months of most years, abundant hard rock fragments in soils, and shallow soils on convex slopes and areas where bedrock orientation aligns with the predominant mountain slopes.

It follows from the above discussion that landscape diversity varies dramatically between the western and eastern portions of the Custer Gallatin. Landscape diversity can be measured by the sum total of geology × terrain × climate differences that exist within a given area of land. Conceptually, it is clear that much greater landscape diversity exists in western portions of the Forest because of the Montane landscape. Landscape diversity may be thought of inversely related to overall land productivity since more diverse landscapes have a greater variety of parent materials and terrain features that increase landscape diversity at times at the expense of timber or grazing potential. The reverse would be true, however, if species diversity were used as the measure of landscape productivity.

Landscape Diversity

The analysis of geology for northern portions the Greater Yellowstone Area was conducted in 2014 as part of the Greater Yellowstone Area Watershed Sensitivity Analysis to potential climate change impacts. This analysis indicated that a total of 98 geology based land management units were in the combined area of Yellowstone and Grand Teton National Parks, Jackson Hole Elk Refuge, Red Rock Lakes Wildlife Refuge, the Gallatin National Forest and those portions of the then Custer and Beaverhead National Forests located within the Greater Yellowstone Area. Analysis of available geology data in this study considered the primary bedrock geology type or types in an area or mode of deposition in non-bedrock controlled areas as the basis for management units. Sixty-seven of those geology units were present on the Gallatin portion of the Custer Gallatin, or 68 percent of the total geologic diversity found in the northern part of the Greater Yellowstone Area. Geology data analyzed for this study came from the Montana Bureau of Mining and Geology and other sources.

This analysis indicates an amazing amount of geologic diversity exists in the Gallatin portion of the Custer Gallatin National Forest. This high level of geologic diversity can be readily seen by looking at the statewide geology map of Montana, specifically the swirl of geologic formations surrounding the north and west sides of Yellowstone National Park. In contrast, Custer Gallatin lands within the Sioux and Ashland Districts plus the Pryor Mountains combined have only a fraction of this level of geologic diversity. Differences in geologic diversity would get compounded once the associated terrain and climate factors are factored into the assessment of overall landscape diversity.

Soil Condition Related to Timber Harvest

A timeline can be built of past ground-disturbing activities on the Gallatin portion of the Custer Gallatin National Forest based on soil disturbance monitoring and field observations. This timeline partitions trends in soil disturbance on the Custer Gallatin into three distinct periods: pre-1965, 1965 through 1993, and roughly 1994 to the present. Trends on the Custer portion of the Custer Gallatin National Forest likely follow a similar path.

Prior to 1965, limitations in the size and power of ground-based equipment kept overall levels of ground disturbance associated with timber harvesting and road building relatively low. By the late 1960s, however, the size and weight of timber harvesting and road building equipment had increased to point where serious ground disturbance was not only possible but became a common occurrence. At the same time, greater demands were being made to increase the level of timber harvesting on national forests. A prevailing idea at the time was that a high level of soil scarification was required after harvesting to ensure the successful establishment of a replacement crop of conifer seedlings, either through germination of existing seed in the soil or more commonly by hand planting. Those three factors combined led to a period where excessive ground disturbance was created due to timber harvesting. Damage was especially severe on soils that, by their very nature, were predisposed to degradation from certain types of ground disturbance.

The period of excessive ground disturbance resulted in increased environmental awareness by the Forest Service and by the public. This led to the application of regional soil standards and use of best management practices by the mid 1990s which helped reduce the impacts from both timber harvesting and road construction. The primary soil mitigation techniques used during this time period included limiting the timing and extent of ground based yarding, rehabilitating timber harvest areas by installing erosion control features along temporary roads, landings and skid trails, and seeding disturbed areas (USDA Forest Service 1988). At the same time, increased litigation was reducing timber harvesting on Forest Service lands. By the end of this period, improved management practices and reduced timber harvesting ultimately led to a substantial decrease in the level of new ground disturbance being created due to timber harvesting on Forest Service lands.

In 1999, the detrimental soil disturbance standard for the Region was adopted and new ideas about timber harvesting such as over-snow logging and partial harvesting became more prevalent. Levels of newly created detrimental soil disturbance dropped off even further. Certain types of prior detrimental soil disturbance such as soil compaction or severe burning can recover naturally over time, provided there initial presence did not result in excessive soil erosion and the loss of valuable surface soil layers. Thus, the reduction in the timber harvesting activity on the Custer Gallatin, decommissioning of roads, and improved site preparation practices were beginning to paid dividends in many areas of the Forest, at least in terms of reduced overall levels of soil disturbance. Overall levels of detrimental soil disturbance on national forest lands, based on both anecdotal evidence and available soil monitoring data were at least stable and potentially beginning to drop.

GIS analysis using the Forest's FACTS database indicates that timber harvesting has occurred on approximately 6 percent of the total acres on the Custer Gallatin. The total acreage figure includes all Custer Gallatin National Forest lands, including designated wilderness and inventoried roadless areas where timber harvest does not occur. The 6 percent figure does not represent the areal extent of past harvesting relative to the total harvestable area on the Custer Gallatin National Forest. In addition, past timber harvesting that was conducted on lands in private ownership before being obtained by the Forest are not included in the current FACTS dataset. These lands represent a fair amount of the overall acreage of past harvesting that has occurred on some portions of the former Gallatin National Forest.

The Custer Gallatin has continued to try new ideas and new design features to improve the recovery of areas most impacted by modern timber harvesting practices, mainly along temporary roads constructed to access timber harvesting areas and at landings.

There are certain types of detrimental soil disturbance, mainly severe soil displacement and accelerated soil erosion that will not disappear over the course of decades, even lifetimes, especially on soil-

landscapes that are highly sensitive to those specific types of disturbance. These areas, although limited in overall extent on the Custer Gallatin, will require more active land restoration measures if they are to recover. Despite a shortage of available resources for this type of work, the Custer Gallatin has been moving ahead on several fronts to address these issues by developing and testing innovative approaches to land restoration.

Projects of greatest interest in this regard are ongoing native grassland restoration work on arid landscapes in the Gardiner Basin, north of Yellowstone Park, and recently planned land restoration trials slated for the North Hebgen Multiple Resource Project on the Hebgen District

Soil disturbance monitoring conducted since 2009 suggests that past mechanical harvest activities across most of the Custer Gallatin National Forest currently complies with Region 1 soil disturbance standards even in many areas harvested before the 15 percent detrimental soil disturbance standard was established in 1999. Exceptions exist in areas where outdated ideas about land scarification and highly sensitive soils converged, such as on portions of the obsidian sand plain near West Yellowstone and in the headwaters of Little Teepee Creek. The experience of harvest administrators and logging contractors as well as geologic, i.e., soil-landscape, differences, season of operation, and the ability to target mitigation measures to the specific type(s) of detrimental soil disturbance, are all factors that influence the final extent of soil disturbance with project areas.

The current protocol on the Custer Gallatin is to wait several years after all timber harvesting and mitigation activities have been completed to assess detrimental soil disturbance conditions after harvesting. This allows most of the more transient, short-term disturbance to recover before assessing actual, post-harvest detrimental soil disturbance levels. Several timber harvest projects have been completed recently, most notably Hebgen Basin and South Bridger, where post-harvest, soil monitoring will be conducted during the coming field season. These data will help inform the Custer Gallatin about the effectiveness of current mitigation measures used on the Forest for those areas harvested most recently.

Legacy soil disturbance from past timber harvesting activities that occurred prior to 1990 persist in many past harvest areas on the Custer Gallatin National Forest. In most of the past harvest areas, legacy detrimental soil disturbance is associated with old landing areas and temporary or jammer roads. Many of the worst disturbances monitored thus far have occurred on the Hebgen and the Bozeman Districts. On the Hebgen District worst impacts were created by Forest Service timber harvesting during the 1970s and 1980s. On the Bozeman District, the majority of highly impacted areas are lands that were obtained by the Custer Gallatin in land exchanges after they were clearcut under private ownership. Overall, monitoring and site assessments indicate that soils where past timber harvesting has occurred are recovering except along old temporary or jammer road corridors, especially when these roads have not been re-contoured, at landings areas, and in high impact areas noted above.

Soil Condition Related to Other Activities

Soils may also be impaired from livestock management, recreation use, mineral exploration, noxious weed invasion, and wildfire. Not all these impacts are covered by the Region 1 detrimental soil disturbance standards which covers only disturbances caused by management activities on lands where vegetation management is a primary management objective. This would include impacts from livestock grazing, recreation use, noxious weed infestations, and possibly mining exploration. Mining operations, administrative areas, and wildfire impacts are excluded from the standard, although impacts caused by wildfire suppression efforts are included.

Soil evaluations on the impact of livestock management draw primarily from range monitoring (see Permitted Livestock Grazing specialist report, [2016]). More recently, detrimental soil disturbance assessments using a soil monitoring approach modified specifically to assess livestock impacts and impacts along riparian corridors was used to characterize impacts from livestock grazing on the Gallatin National Forest. These assessments found low levels of detrimental soil disturbance (less than 2 percent) but the areas sampled by no means represent all grazing areas and/or riparian areas on the Forest. Several drainages in the South Bridger Range Allotment were monitored in this manner in direct response to public comment indicating that “clay” soils along riparian corridors in the area were being adversely impacted by livestock grazing. Not only were the levels of detrimental soil disturbance low but soils along the drainages monitored were almost entirely sandy due to the predominant volcanic bedrock in the area.

On the Custer side of the Custer Gallatin, past analyses found consistently low levels of detrimental soil disturbance that was primarily concentrated along fences and in areas where livestock water (for example, Houston (2012), unpublished Forest Service memo). A level of uncertainty exists in these data since the analysis lacked sampling in undisturbed reference areas. The Ashland and Sioux Districts have permitted livestock grazing ever since these lands were first placed under Forest Service management.

Recreation impacts can degrade soils when heavy use and poor trail placement result in the trail tread becoming rutted or multiple treads are created due to wet soil conditions. Additional detrimental soil disturbance is created when erosion along a trail cut into previously undisturbed soils or where user-created non-system trails are constructed. Multiple auxiliary disturbances can occur associated with trail erosion, drainage of adjacent moist meadows, and the advance of noxious weed infestations along trail corridors. The same can be said for user created, 4-wheel drive routes and dispersed use of motorcycles, all-terrain vehicles, and trucks off of established roads and trails. Detrimental soil disturbance is also created at large dispersed campsites on the Custer Gallatin.

Currently impacts from off road vehicle use are most prevalent in the Bangtail Mountains and around Flathead Pass on the Bozeman District and the Benbow area of the Beartooth District. User-created recreation trails lack adequate design to shed storm water and are often created on sustained, steep grades prone to erosion.

Another source of soil disturbance prevalent on certain areas of the Custer Gallatin is infestation of lands by noxious weed species. Weed seed when it becomes prevalent in surface soil horizons becomes a biological factor of the soil that has the potential to reduce land productivity and restrict management options. Strong correlations have been found on the Custer Gallatin, especially on certain soil-landscape types, between past soil disturbance and the occurrence of noxious weeds. These infection sites then become source areas for the spread of noxious weeds into adjacent, non-disturbed areas. Noxious weed spread can follow disturbance since weeds have opportunistic traits and can exploit disturbed soil conditions (Williamson and Harrisburg 2002; Norton et al. 2007; James et al. 2010) typical of many pioneer species. The expansion of weed infestations into new areas can alter nutrient regimes and organic carbon levels in the soil which shifts the competitive balance on a site away from desired native species (Wolf and Klironomos 2005; Steinlein 2013). Management options and growth potential are both reduced when weed infestations exceed thresholds where restoration becomes difficult, creating new novel plant assemblages (Seastedt et al. 2008).

Once a noxious weed becomes a co-dominant species on a site, whether in a grassland area or as a forest understory plant, changes to the soil and reduced site potential are consistent with the concept of “permanently degraded” as used in the National Environmental Policy Act (1970) and the National

Forest management Act (1976). Without management action to reverse the negative effect of noxious weed infestation these areas can become permanently degraded.

Mineral exploration is an integral component of commodity production on the Custer Gallatin that commonly requires excavation of soil and rock across a contiguous area. During extraction, minerals activities are not managed for vegetation growth so are not covered by the Region 1 detrimental soil disturbance standard. That standard should apply, however, after mining activities are finished and all land restoration actions have been completed since the goal of land restoration is to re-establish native plant communities that will be managed for vegetation growth.

Wildfires continue to impact the Custer Gallatin National Forest that bring tradeoffs of benefits to the soil resource associated with the cycling of organic carbon and the release of nutrients into the soil versus the loss of protective ground cover exposing soils to potential accelerated soil erosion during the recovery period. Providing adequate time for soils recovery in the face of continued management needs, such as cattle grazing and commercial timber harvest, can be an ongoing challenge for the Custer Gallatin. Further, as dead trees fall to the forest floor and accumulate, excessive fuel loading may in some instances constitute management concern from a public and firefighter safety perspective. Alternatively, coarse woody debris left behind in the form of partially burned tree trunks represent a valuable source of organic substrate materials that can facilitate the growth of conifers, improving site fertility, and providing habitat for symbiotic micro-organisms in the soil that aid in conifer uptake of water and nutrients. Coarse woody debris also provides microsites for conifer establishment, may retain moisture on the site and can reduce soil erosion from thunderstorms. Management of these organic materials requires an assessment of the relative benefit of removal versus lost opportunity to improve site productivity.

Soil Condition Assessment by Landscape Area

Madison, Henrys Lake, Gallatin and Absaroka-Beartooth Mountains

Inherent Soil Productivity. Natural soil productivity in this area varies in response to changes in terrain as well as underlying geologic material. Soil conditions are generally cold and dry, with limited soil depth on rocky or convex slopes and abundant rock fragments in most soils. Most years, low soil temperatures limit tree growth during early spring months while dry conditions limit growth during the late summer and early fall. About 74 percent of this landscape area is designated as wilderness or inventoried roadless areas. Thus, for much of the area land productivity relates primarily to the ability of the land to support desired vegetation for watershed, wildlife, fisheries, and recreation purposes.

Landscape Diversity. Very high to high in most areas due to variable geology, terrain, and climate conditions.

Detrimental Soil Disturbance. Impacts persist where past timber harvesting has occurred outside of wilderness or designated roadless areas. Most past timber harvesting occurred during a period from the late 1960s through early 1990s with clearcutting as the preferred harvest method. Ground scarification was thought to be essential to the re-establishment of conifers after harvesting, either through natural regeneration or more commonly planting young seedlings.

Soil monitoring since 2009 indicates that current pre-existing levels of detrimental soil disturbance associated with past regeneration harvests (clearcutting) generally ranges from about 8 to 12 percent detrimental soil disturbance within harvest units. Intermediate harvests such as commercial thinning, shelterwood or patch clearcut harvests, result in approximately 4 to 8 percent detrimental soil

disturbance. Partial harvests, single tree, group selection, or salvage cutting have pre-existing detrimental soil disturbance levels in the 1 to 4 percent range. Monitoring of over-snow logging and areas where mastication has recently been conducted result in current detrimental soil disturbance levels of 1 to 3 percent.

Several areas of excessive soil disturbance, exceeding the Region 1 maximum standard 15 percent detrimental soil disturbance, have been found where clearcutting and excessive ground scarification occurred on soils that are highly sensitive to soil displacement or surface soil erosion. These are found on portions of the obsidian sand plain around West Yellowstone and the headwaters of Little Teepee Creek, north of Hebgen Lake.

As a point of interest, similar types of soil disturbance were found in the volcanic bedrock areas of Rendezvous Trail vegetation management project with soil conditions similar as those in the headwaters of Little Teepee Creek. Both areas have volcanic ash caps but the volcanic soils in the Rendezvous Trail area have a volcanic ash cap that is deep enough so the dozer piling that occurred did not expose rocky, substrate materials. Disturbance in the Rendezvous area had no apparent effect on lodgepole pine growing there because this site had one of the best lodgepole pine site indices observed on the Custer Gallatin during soil monitoring.

Soils in wilderness or inventoried unroaded status have, for the most part, very limited amounts of activity caused detrimental soil disturbance. The detrimental soil disturbance that is present is primarily associated with recreation use in these areas although some evidence of past mining activity remain in several locations. Outside of wilderness, off-road vehicle use and non-system trails have degraded soil in a number of areas, including the Beartooth District's Benbow area and past mining impacts can still be seen in several locations.

Limited data are available on the Beartooth District of the former Custer National Forest to evaluate extent of past ground disturbance associated with either past or current timber harvesting. Very little ground-based timber harvesting has occurred on the Beartooth District over the past 10 years. Detrimental soil disturbance evaluated immediately post-harvest was found to be in excess of 15 percent in one area sampled (Lane 2011) and as low as 3 percent in areas monitored more recently (Efta 2015, unpublished data).

Past timber harvest monitoring was conducted in 2013 and 2014 across a range of proposed harvest units in the greater Red Lodge area. Only a portion of these had been previously harvested. Detrimental soil disturbance in monitored treatment units was limited in extent.

Soil Erosion. Major disturbance from wildfires and subsequent storm wash create the main source of sediment delivered to drainages on this portion of the Custer Gallatin. Major soil erosion events do occur associated with natural landslide events. These are especially prevalent in the Taylor Fork drainage which periodically contributes substantial sediment loads to the Gallatin River. Landslides and numerous slumps occur elsewhere in on the Custer Gallatin which at times delivers sediment to local drainages. These are often associated with underlying shale bedrock beneath more porous rock layers.

Debris flows can occur on very steep slopes, especially after major wildfires. Recent wildfires in the headwaters of Storm Castle and Emigrant Peak areas each caused major soil erosion events due to debris flows. In 2010, a high intensity thunderstorm event produced significant debris flows in tributary drainages to the West Fork of Rock Creek inside the 2008 Cascade Fire burn perimeter.

Areas of high soil erosion can also exist where management actions result in extensive amounts of bare ground. The Custer Gallatin has decreased the overall area of management-caused bare ground on the Forest by directly closing roads and returning the old road surfaces to more natural slope contours.

Bridger, Bangtail, and Crazy Mountains

Inherent Soil Productivity. Soil productivity in this landscape area is also highly variable due to factors such as diverse terrain conditions and complex patterns of natural soil erosion and deposition. Productivity varies by aspect and elevation in response to gradients of temperature and effective precipitation. Cold soil temperatures limit conifer growth in the spring of most years, while dry soil conditions often limit productivity during the late summer and early fall months. The steep rocky terrain and convex slopes, indicating shallow soils, limit site productivity in sandstone, limestone, and volcanic bedrock portions of this area as do abundant rock fragments in some soils.

At the same time, downwind deposition of sediment from the steep rocky slopes above has deposited sediment below on the northeast side of the Bridger Mountains, not unlike deposition of snow on those same slopes during the winter. It is unknown at this time if the same pattern of erosion and downslope deposition occurs on ridges and east trending slopes in the Crazy and Bangtail Mountains as well. Similar orientation of these mountain ranges suggests that may be the case. Deposition on leeward slopes, where present, greatly increases overall site productivity in these areas.

About 40 percent of this landscape area is in designated roadless areas limiting the overall level of soil disturbance for the area as a whole. However, some areas were clearcut in a manner that created excessive soil disturbance while under in private ownership which have since been obtained by the Forest Service in land exchanges. A number of these areas, still have a reduced levels of soil productivity due to past soil disturbance. These areas are recovering slowly at best with infestations by noxious weeds a primary impediment to recovery. This is especially noticeable on the east side of the Bridger Mountains and in parts of the Bangtail Mountains. Additional soil monitoring needs to be conducted in these areas. Invasive weeds, off-road vehicle use and non-system trails have degraded soils in several other areas, most notably in the Bangtail Mountains and Flathead Pass.

Landscape Diversity. A moderate level of landscape diversity exists in this landscape area. While the makeup of geologic strata, terrain, and climatic patterns varies somewhat between mountain ranges, landscape patterns remains fairly constant within each individual range.

Detrimental Soil Disturbance. Soil monitoring and field observations found high rates of disturbance from old timber harvest where ground-based equipment was used along the east side of the Bridger Mountains and in portions of the Bangtail Mountains. High rates of soil disturbance most often occur on Forest Service lands that were in private ownership when they were clearcut. A portion of these areas likely exceed the 15 percent detrimental soil disturbance standard. It will take a long time for some of these areas to recover, but unlike the areas in the West Yellowstone area, these impacts were on productive soils that have the potential to recover with proper management. Soil recovery from past disturbance may be delayed by weed infestations of Canada thistle and houndstongue, or spotted knapweed depending on soil-landscape type that interferes with native plant community succession. The Bridger and Bangtail Mountains have the highest risk for weed infestations when are disturbed, especially in moist meadow areas. Current soil conditions in the Crazy Mountain Range on prior private lands recently acquired by the Forest Service are generally in better condition than those with similar past ownership in the Bridger and Bangtail Mountains. Pre-existing detrimental soil disturbance levels in the Smith Creek and Shields River areas, that were harvested previously while in private ownership, have detrimental soil disturbance levels ranging from 4 to 12 percent.

Areas with excessively high ground disturbance in newly acquired private timber lands resulting from of past clearcutting, road building, and excessive soil scarification during site preparation in the 1970s and 1980s has left impaired soil conditions. Prior studies indicate that the soil disturbance imprint was larger prior to the 1990s (Klock et al. 1975; Clayton 1990), but forest specific monitoring was not regularly used until the late 2000s to substantiate these findings. Much of these newly acquired lands are especially susceptible to soil compaction and/or displacement based on inherent properties of surface and near-surface, mineral soil layers.

Soil Erosion. Most of the soil disturbance in these island mountain ranges is now 20 to 40 years old. Soil erosion is more of a short-term response to land disturbance, unless entire hillsides have been denuded of vegetation. Thus, even in areas with major past disturbance, soil erosion rates have likely dropped off significantly during the time since disturbance. An exception would be during extraordinary rainfall and/or landslides events where an entire drainage channel may get sluiced out from debris and high water flows during these episodic events which are most likely occur on the west side of the Bridger and Crazy Mountains.

Overall, soil erosion levels in the Bridger, Bangtail, and Crazy Mountains will remain low except after periodic disturbance from wildfire, flood or landslide events. The trend for recovery in past harvest areas within the newly acquired forest lands will be slow where high soil disturbance still persists.

Pryor Mountains

Inherent Soil Productivity. Detailed information about soil and land productivity in the Pryor Mountains is lacking at this time. In general, vegetation growth in this area is limited by dry conditions during late summer and early fall months of most years, very rocky soils, and a high proportion of shallow soils. Cold soil temperatures in the spring, in contrast with Forest areas further west, are likely not an issue. Southern portions of the Pryor Mountains receive distinctly less precipitation than the north end of the area. This strong moisture gradient, coupled with dominantly south-facing terrain, results in a substantial difference in land productivity from north to south between the Sage Creek Canyon and area draining Big Pryor Mountain. Areas falling within the Sage Creek drainage are dominated by Douglas-fir/lodgepole pine overstory interspersed with grassy meadows. In contrast, vegetation across the most southerly portion of Forest Service-managed lands in the Pryor Mountains are more reminiscent of desert landscapes with sparsely vegetated, rabbitbrush and sagebrush dominated landscapes.

Landscape Diversity. The Pryor Mountains have moderate geologic diversity resulting from mixed strata of sandstone, limestone, and to a lesser extent, shale. When combined with the moisture gradient noted above, this results in overall moderate levels of landscape diversity as well.

Detrimental Soil Disturbance. Only a limited amount of detrimental soil disturbance data has been collected in the Pryor Mountains. Field reconnaissance was done to evaluate soil conditions for the Sage Creek and Red Butte Allotment Management Plans NEPA analysis. The assessment found slight soil compaction across the Sage Creek Allotment likely attributable to historic and ongoing cattle grazing (Houston 2012, unpublished report). Additional soil damage has occurred in the Sage Creek area from excavation, bulldozing, and tree removal associated with a recent unauthorized private landowner fenceline realignment onto National Forest System lands (Efta 2013, memo).

Although timber harvesting activity has not occurred since the 1980s, nearly all of this area has been used for cattle grazing. Soil monitoring has been limited in most livestock grazing areas, so the full extent of soil disturbance is unknown. The most recent timber sale activity within the Pryor Mountains

in the 1980s covered approximately 900 acres in 1980. Soil monitoring remains to be completed in this past harvest area.

Soil Erosion. The property trespass discussed above has contributed to accelerated soil erosion in the areas affected. The Pryor Mountains have also experienced debris flows in recent years under both pre- and post-wildfire conditions (Efta 2013; Neinow 2011). Given the difference in bare soil extent, soil erosion is likely naturally elevated across the southern portion of the National Forest System-managed lands as compared to the Sage Creek drainage.

Ashland District

Inherent Soil Productivity. Inherent land productivity on the Ashland District ranges from low to moderate. Most of the area is mapped as having a semi-arid soil moisture regime, where water is limiting to plant growth for extended periods during in most years. The soil survey shows slightly high elevations and northern aspects as having improved soil moisture conditions with 15 to 19 inches average annual precipitation (Western Regional Climate Center 2016), in an “ustic” soil moisture regime where soil moisture is limiting later in the growing season of most years but most precipitation falls during spring and early summer months. The higher precipitation in these areas correlates to substantially higher productivity relative to low lying areas. Elsewhere, the semi-aridic soil moisture conditions exist with 10 to 14 inches average annual precipitation. Reduced land productivity exists in these areas. Very shallow soils on steep bench slopes and saline or sodic soil conditions in soil areas contribute low overall productivity in lower elevation areas.

Steep, confined draws maintain more favorable soil moisture conditions relative to surrounding areas that hold snow longer and receive run-in soil moisture from upslope areas. These highly productive areas support woody riparian vegetation and often produce intermittent or even perennial surface water flow.

Landscape Diversity. The sedimentary plains overall have low levels of landscape diversity due the limited amount of different geologic materials present, primarily sandstone and shale along with local alluvium formed from sandstone and shale. Topography varies mostly at local scales which are reflected in local plant communities. Local areas of scoria or clinker rock add visual diversity to the landscape where present.

Detrimental Soil Disturbance. The typical range in detrimental soil disturbance found has been between 1 to 3 percent detrimental soil disturbance for past winter harvesting areas, partial timber harvesting, and rangeland areas, as well as areas sampled by Robinson (2011). However, this area has only had a limited amount of soil disturbance sampling conducted to date so it is difficult to extrapolate these data to the areas as a whole.

Soil Erosion. Local areas of active soil erosion exist on the Ashland District. The entire landscape is largely the result of variations in the hardness and erodibility of the predominantly sedimentary rock geology. Although much of the area tends to be high erosive due to the semi-arid climate, short slope lengths provide some control on overall soil erosion levels. Higher elevation levels and north facing slopes tend to have lower soil erosion levels due more favorable soil moisture conditions greater vegetation cover.

During the 2012 wildfire season, greater than 150,000 acres of the district burned. In 2013, record-setting precipitation was encountered across southeast Montana, yielding widespread erosion and debris flows. Soils continue to stabilize in burned areas as vegetation recolonizes postfire bare areas

(Efta 2015; also North Whitetail Categorical Exclusion Soils specialist report). Recovery is slower on the soils in scoria geology. As of field season 2016, soils in scoria areas that burned under high severity still had a high amount of bare soil present.

While the district has reduced the permitted animal unit months over time, every acre of the Ashland District is still allocated towards livestock grazing. Numerous cattle trails persist across the district. Soil damage from livestock is most evident around stock tanks where livestock congregate. These bare areas have compacted conditions that no longer supports vegetation growth.

Preliminary data exists that indicates extensive livestock grazing on portions of the Ashland District may have negatively impacted site productivity through compaction of surface soil layers and a corresponding decrease in rooting depths. Further study is planned using soil indicators of soil health (Herrick et al. 2002) to assess potential impacts.

Sioux District

Inherent Soil Productivity. Inherent land productivity on the Sioux District ranges from low to moderate. Controls on productivity are generally similar to the Ashland District. While still largely comprised of horizontally bedded sedimentary bedrock, the Sioux District contains more diverse bedrock geology than the Ashland District. Mapped formations include the Arikaree Formation, Fort Union Formation-Ekalaka Member, Fort Union Formation-Ludlow Member, Ludlow Formation (synonymous with the Fort Union Formation-Ludlow Member in MT USGS survey), Hell Creek Formation, and White River Group (South Dakota Geological Survey 1952). Alluvium and landslide deposits have also been mapped across the district. Coal does not comprise a significant proportion of bedrock geology across the Sioux District.

The Harding County Soil Survey used ustic soil moisture regime map units for areas receiving between 15 to 19 inches of mean annual precipitation, and an aridic intergrade ustic for areas receiving between 10 to 14 inches of mean annual precipitation. These are split largely based on elevation and aspect differences at a local scale. Ustic higher productivity soils occur on higher elevations and north facing slopes. Productivity declines on lower elevation and south aspects. Very shallow to shallow soils on bench slopes and low lying sodic or saline areas have low productivity.

Landscape Diversity. The plains have low diversity in landscapes from the flat lying sandstone and shale bedrock or local alluvium formed from sandstone and shale. Topography can vary dramatically over short distances but landscape patterns are often repeated over large areas. Several prominent plateaus are located on Custer Gallatin lands that add greater variability to the local environment around them. Patterns of plant community can vary strongly on a local level due to variations in local soil, geology and terrain conditions.

Detrimental Soil Disturbance. The Custer Gallatin National Forest lacks soil monitoring information on the Sioux District.

Soil Erosion. With portions of the Sioux District best characterized as badlands—comprised of mostly bare, readily erodible sedimentary bedrock drained by ephemeral draws—active erosion is common. The entire landscape is largely the result of variations in the bedrock hardness and erodibility of the rock types present. In general though, slope lengths in steep areas are short and much of the eroded sediment gets stored in the surrounding landscape. Similar to the Ashland District, elevated post-wildfire soil erosion is a natural periodic disturbance process.

Riley Pass, falling within the North Cave Hills Unit of the District, was the site of a historic uranium mine. During the 1950s and 1960s, surface soil was bulldozed off the tops of a series of bluffs, lignite coal deposits were burned off, and uranium was extracted across approximately 250 acres. The mine was abandoned and is currently managed under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) site by the Custer Gallatin National Forest.

Radioactive soils persist on the site. Soils in the area are largely devoid of vegetation. Given the high intensity thunderstorms that are common throughout the region, the area has been subject to heavily exacerbated erosion and downslope sedimentation. Expansive gullies have formed, one in excess of 20 to 30 feet wide and deep, along the bases of the affected bluffs. Reclamation activities are ongoing. Currently, mine waste is being placed into repositories and covered with borrowed topsoil from adjacent private lands.

Extensive erosion and land clearing at Riley Pass, as discussed above, has permanently reduced soil productivity across much of the affected area.

Two oil and gas producing wells exist on the district, both in Fuller Draw in the North Cave Hills.

Information Needs

The information needs identified in this section would provide for more effective management of the Custer Gallatin. They are not necessary for revising the existing plans.

Existing Soil Disturbance and Related Data

- A comprehensive analysis of past harvest data on the Custer portion of the Custer Gallatin needs to be conducted and additional detrimental soil disturbance collected to adequately cover the full range of past timber harvest types and intensity that have been used over the last 50 years.
- Additional detrimental soil disturbance data needs to be collected on both sides of the Custer Gallatin utilizing current Custer-Gallatin National Forest standard soil monitoring procedures.
- Existing, post-2008 detrimental soil disturbance data in project files for the Gallatin portion needs to be compiled into a separate Custer Gallatin-wide database.
- Pre-2008 detrimental soil disturbance data on the Gallatin and all currently available detrimental soil disturbance data for the Custer will subsequently added to the database but flagged as utilizing a more qualitative, judgement based, approach.
- Past harvest data on the Gallatin portion of the Custer Gallatin (and possibly the Custer) need to be made more readily usable for planning project-level detrimental soil disturbance monitoring and distributing soil monitoring results.

Soil Survey Information

- Complete the soil survey for the Absaroka-Beartooth Wilderness area and adjacent, non-wilderness areas of the Beartooth District utilizing a modelling approach, existing soil profile data, and limited additional field reconnaissance and targeted soil profile sampling.
- Update the current version of the Gallatin National Forest Soil Survey utilizing the same basic soil modeling and field procedures noted above.
- Create a single, high quality, variable scale, soil survey covering the entire Custer Gallatin National Forest by first updating the county-wide soil surveys covering all remaining lands on the

Custer portion of the Custer Gallatin and then combining the three soil surveys into a single coverage.

- Soil survey information, updated or otherwise, for the entire Custer Gallatin needs to be made more readily available, understandable, and transparent so it can potentially be utilized by Forest managers, staff, and the public.

Key Findings

- Forest plans for both the Custer and Gallatin portions of the Custer-Gallatin National Forest provide limited direction with respect to the management of soil resources. Greater direction in the forest plan will help ensure that positive steps taken by the Custer Gallatin to maintain and improve soil productivity will be carried forward through the next planning period.

Soil Productivity Potential

- The ability of soils to produce desired types and amounts of native vegetation varies across the Custer Gallatin at many scales. Of primary interest from a project activity basis is variability at the landscape scale and at the more site-specific, landscape-component scale. Soil productivity is limited to some extent in all areas of the Custer Gallatin due to one or more terrain, soil, and or climate constraints.
- Forest lands on the east side are characterized as warm and dry. Limited soil moisture during late summer and early fall months of most years and abundant shallow soils on many bedrock controlled landscapes, as well as saline or sodic soil conditions in lower elevation shale areas, are the primary factors limiting soil productivity.
- Inherent soil productivity over most of the western two-thirds of the Custer Gallatin can be characterized as limited by a cold-dry climate, steep terrain, and abundant shallow or rocky soils.
- Climate-based limitations to soil productivity, dry soils in the later part of the growing season, and cold soils early in the growing season, have important implications with respect to the management of coniferous forests.
- Landscape diversity varies dramatically between the western and eastern portions of the Custer Gallatin with much higher levels of landscape diversity on the west side of the Custer Gallatin (Beartooth District west).

Management Caused Reductions in Soil Productivity

- On the Gallatin portion of the Custer Gallatin, only detrimental soil disturbance data collected after 2008, utilizing refined detrimental soil disturbance criteria specific to soil conditions on the Gallatin, provides results that are consistent with past timber harvest levels and observable detrimental soil disturbance levels in the field.
- Limited detrimental soil disturbance data exists on the Custer portion of the Custer Gallatin. These data consistently indicate low levels of detrimental soil disturbance in activity areas but may not accurately reflect the full range of past timber harvesting by harvest type that has occurred on the Custer.
- The normal range of detrimental soil disturbance found on most areas the Gallatin by past harvest type are: 8 to 12 percent for most past clearcut or comparable regeneration harvests; 4 to 8 percent for intermediate harvests such as commercial thinning, shelterwood or patch

clearcut harvests; and 0 to 4 percent for partial harvests, single tree selection, group selection, or salvage cutting.

- Legacy high impact areas exceeding the Region's 15 percent detrimental soil disturbance standard have been found in several locations on the Custer Gallatin, including upper Little Tepee Creek, the obsidian sand plain near West Yellowstone, and several areas where the Custer Gallatin obtained lands through land exchanges that were previously clearcut while under private ownership. The amount of detrimental soil disturbance in these areas varies from approximately 18 percent to 32 percent. In all instances the high levels of detrimental soil disturbance created are the result of a combination of soil-landscapes that were highly susceptible to specific types of detrimental soil disturbance and the use of excessive ground scarification practices associated with clearcutting.
- The limited amount of soil monitoring conducted in active grazing and riparian grazed areas shows low levels of detrimental soil disturbance (less than 2 percent), but the areas sampled do not provide a representative sample of all grazing areas and/or riparian areas on the Custer Gallatin.
- Soils vary in their susceptibility to specific types of detrimental soil disturbance as well as their ability to recover from disturbance either naturally or as a result of mitigation actions.
- Recovery response curves vary among the different types of detrimental soil disturbance and the severity of disturbance. They are also affected by the local soil-landscape type.
- Some types of detrimental soil disturbance, such as excessive soil erosion or soil displacement on soils highly susceptible to degradation will not recover unless active land reclamation actions are implemented.
- Based on current trends and management direction, weed infestations and user-built mountain bike trails running straight up and down steep slopes will increasingly create new areas of detrimental soil disturbance in the future.

Soil Resource Inventories/Soil Surveys

- Multiple soil surveys of varying ages, resolution, accuracy, and scale cover most areas of the Custer Gallatin National Forest.
- A large hole in the existing soil survey coverage for the Custer Gallatin exists, including the Absaroka-Beartooth Wilderness and adjacent, non-wilderness lands of the Beartooth District.
- No Terrestrial Ecological Unit Inventories currently exist for any portion of the Custer Gallatin, although detailed vegetation data was collected by Montana State University for the Custer portion of the Absaroka-Beartooth Wilderness and adjacent areas. These data were collected in anticipation of creating a Terrestrial Ecological Unit Inventory. Point sample soils data collected in this effort, however, do not meet required National Cooperative Soil Survey standards for a certified soil survey of the area. Without a certified soil survey, the Terrestrial Ecological Unit Inventory itself must meet the National Cooperative Soil Survey standards.
- Any future inventory of soil resources or updates of existing soil surveys on Forest Service lands, should be based on the primary soil forming factors, climate, geologic parent materials, and terrain that largely determine the types and distribution of soils on the Custer Gallatin, in conjunction with a soil modeling and variable map-scale approach.

- Questions of appropriate resolution, accuracy, mapping scale, and relevance to Custer Gallatin management activities will dictate “best available science” in regard to future soil surveys or other land resource inventories conducted on Forest Service lands.
- The concept of soil-landscapes has been increasingly used for project-level NEPA analyses on the Gallatin portion of the Custer Gallatin National Forest. This concept and associated data would be used as the base 1:100,000 data layer in a variable-scale soil survey.
- Terrain analysis results and a soil-management-geology coverage have already been created for all lands on the Gallatin and part of the Custer portion of the Forest as part of the Greater Yellowstone Watershed Sensitivity to Climate Change analysis. These will both be instrumental dataset for soil survey modelling.
- Soil Scientists on the Custer-Gallatin National Forest need to take a much more proactive approach to make needed soils information both more relevant to Forest management issues and understandable to all potential users of this information beyond NEPA reports.

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